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12.5 High-Efficiency Particulate Air (HEPA) Filter System Design for LLNL Applications

(Formerly H&SM S12.05)

Recommended for approval by the ES&H Working Group

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New document or new requirements

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12.5

High-Efficiency Particulate Air (HEPA) Filter System Design for LLNL Applications*

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* **Minor revision**

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High-Efficiency Particulate Air (HEPA) Filter System Design for LLNL Applications

1.0 Introduction

This document provides information and requirements regarding the selection, installation, operation, testing, and replacement of fixed high-efficiency particulate air (HEPA) filter exhaust ventilation systems. The primary purpose of this document is to assist ventilation engineers and facility managers in designing and maintaining HEPA filter systems.

This document addresses use of HEPA filters that are installed in ventilation systems used to protect workers, the public, and the environment from significant exposure to highly hazardous (e.g., significantly radioactive, carcinogenic, beryllium) aerosols in effluent streams. (The ES&H Team can provide guidance on which hazardous material effluent streams require HEPA filters.) HEPA filters are required for radiological Type III workplaces. With two exceptions, this document does not address the use of HEPA filters used for clean room or housekeeping applications or applications that are addressed separately in the *LLNL Environment, Safety, and Health (ES&H) Manual*, (i.e., biological safety cabinets, HEPA-filtered vacuum cleaners, and asbestos/lead abatement). The exceptions are:

- HEPA filters used for housekeeping purposes for radioactive, carcinogenic or other highly hazardous aerosols must meet the labeling requirements shown in Fig. 2. The maximum age of any such filter should be ten years from date of manufacture or, if this date is not available, the date the filter arrived.
- Vacuum cleaners and other portable equipment with HEPA exhaust filters used to handle hazardous substances can be procured only if the HEPA filters can be tested annually for leakage using light scattering aerosol photometers and challenge aerosol. Procurement of such equipment through any channel shall be reviewed and approved by the Hazards Control Industrial Hygiene Instrument Laboratory (IHIL) prior to procurement. To approve a procurement action, IHIL shall obtain certification from the manufacturer or vendor that the equipment can be tested in this way as well as guidance about how the tests are run. Alternatively, IHIL may rely on experience with testing the same make and model of equipment already at LLNL.

2.0 Control Measures

2.1 HEPA Filter Specifications

All HEPA filters covered by this document shall meet the specifications found in DOE-STD-3020-97 (*Specification for HEPA Filters Used by DOE Contractors*).

2.2 Certification of Filters and Initial Leakage Testing of Systems

Prior to installation, a HEPA filter is certified with a minimum particle removal efficiency of 99.97% for thermally generated, monodisperse dioctyl phthalate (DOP) particles with diameters of 0.3 μm. The leakage tests described in Section 2.5 are done using polyalpha olefin (PAO) rather than DOP due to concerns about the potential carcinogenicity of DOP.

2.3 Description

The typical filter consists of a wood or metal frame or box with a filter core. The filter core is usually made of corrugated aluminum separators covered by interwoven filter medium; this forms air passages between folds of the medium (see Fig. 1). Some open-face filters have wire guards on each face to protect the medium from damage.

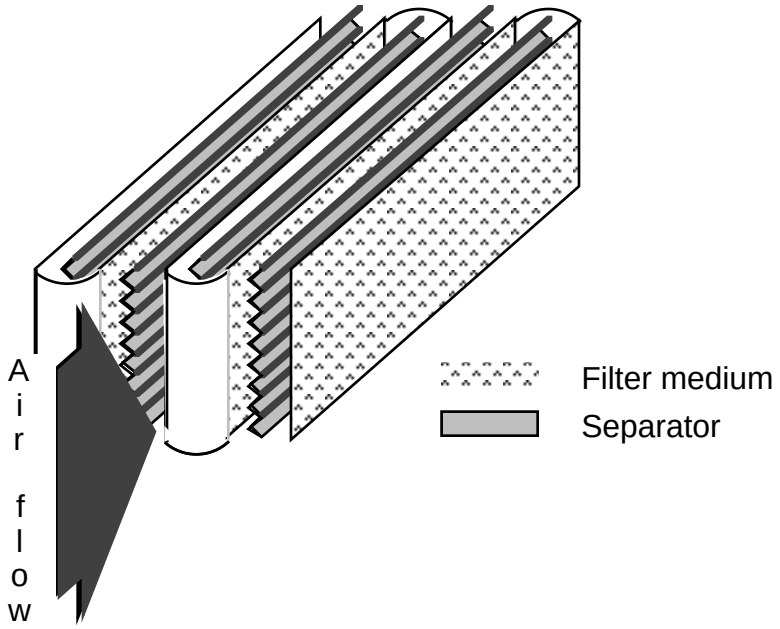


Figure 1. Typical filter configuration.

Two configurations are commonly used to connect the filter to the ventilation system: open-face and closed-face. LLNL's stock filter sizes for open-face filters are shown in Table 1. An open-face wood frame filter has gaskets for seals. An open-face metal frame filter either uses Blu-Jel (or equivalent) as a seal or has a gasket seal. A closed-face filter is supplied with transition fittings on both faces for attachment to the ducts; the transition sections and the filter housing form part of the system pressure-boundary. Closed-face filters are no longer allowable for applications within the scope of this document, as specified in Lawrence Livermore National Laboratory HEPA Filter and In-place Leak Testing St*andard (*UCRL-AR-133354) and the references in Section 5.0. Closed-face filters shall be taken out of service and replaced by open-face filter installations following the implementation plan in Appendix B.

Table 1. Dimensions, nominal airflow ratings, and maximum resistance for typical HEPA filters[a].

Size	Dimension in. (mm)	Nominal airflow		Maximum resistance		Filter weight lb	LLNL Stock No.
		cfm	m^3/hr	In. water gauge	Pa		
1	8 × 8 × 3 1/16 (203 × 203 × 78)	25	42	1.3	325		
2	8 × 8 × 5 7/8 (203 × 203 × 149)	50	85	1.3	325	3.6	4170-33091[b]
3	12 × 12 × 5 7/8 (305 × 305 × 149)	125	212	1.3	325		
4	24 × 24 × 5 7/8 (610 × 610 × 149)	500	850	1.0	250	17.0	4170-33092[b]
5	24 × 24 × 11 1/2 (610 × 610 × 292)	1000	1700	1.0	250	32.0 40	4170-33093[b] 4170-70010[c]
6	24 × 24 × 11 1/2 (610 × 610 × 292)	1250	2125	1.0	250		
7[d, e]	24 × 24 × 11 1/2 (610 × 610 × 292)	1500	2550	1.3	325		
8[f]	24 × 24 × 11 1/2 (610 × 610 × 292)	2000	3400	1.3	325		
9	12 × 12 × 11 1/2 (305 × 305 × 292)	250	425	1.0	250		

[a] From DOE-STD-3020-97. Open-face filters only.

[b] Gasket seal

[c] Fluid seal, steel frame

[d] Constructed with separators

[e] Constructed without separators

[f] Mini-pleat design

The components of the filter are discussed briefly below:

Frame. The frame or box is made of 3/4-in. exterior plywood or steel cladding. The plywood is treated for fire resistance.

Note: Particleboard construction is not allowed for new installations.

Filter medium. The filter medium is made of glass fiber containing a 7% maximum of combustible material or other materials that could cause shrinkage of the medium at elevated temperatures. The medium is ≥0.015-in. thick.

Separators. The separators are usually made of corrugated aluminum sheeting with a minimum thickness of 0.0015 in. Acid-resistant separators are available, but they are not LLNL stock items. Separatorless filters are available and becoming more common. These have higher flow ratings than conventional HEPA filters, but have lower static pressure resistance.

Sealant. The sealant used to seal the filter core into the frame is a heat-, moisture-, oil-, and ozone-resistant elastomeric adhesive or a self-extinguishing urethane foam.

Wire guards. The guards are made of galvanized hardware with 1/4-in. mesh. The wire guard is secured to the frame with a bead of adhesive. New open-face filters shall be equipped with these guards.

Face-edge seals (open-face filter only). Two methods are employed for sealing the HEPA filter into the housing:

- *Gaskets.* The gasket is made of 1/4 in. thick, 3/4 in. wide, closed-cell, expanded neoprene rubber. The gasket is attached to each face of the filter in a manner that will assure a continuous seal around the frame and produce a leak-tight joint. Fire-retardant, rubber-base adhesives are used for gluing gaskets to the frame.
- *Fluid seal.* The sealant is an inert, non-Newtonian fluid that fills a continuous channel or routed groove, which is 3/8 in. wide and 3/4 in. deep, on the face of the filter frame.

Transition fitting (closed-face filter only). The inlet and outlet transition fittings are made of steel sheeting. The fittings are secured to the frame with adhesive, screws, or a combination of both to form a leak-tight joint. The fittings are designed to withstand either a 200-lb axial load or a transient lateral load. The fitting becomes part of the pressure boundary.

2.4 Design and Installation Considerations

All ventilation systems in hazardous applications at LLNL must follow the requirements in "HVAC Systems in Nonreactor Nuclear Facilities" (UCRL-AR-133352). The *Nuclear Air Cleaning Handbook* (ERDA, 1976) provides more specific guidance on system design and HEPA installation. Major highlights of this handbook are presented in Sections 2.4.1 through 2.4.6.

2.4.1 Installation

The HEPA filter unit must be properly connected to the system to prevent leakage. It shall be designed and installed in such a manner to provide safe and easy access for testing and inspection, as well as easy replacement. Compressed air and 110 VAC need to be readily available nearby (ideally within 25 ft) for periodic testing. The HEPA filter shall be tested as described in Section 2.5.

Note: The media of all filter units should be mounted with pleats vertical rather than horizontal to prevent sagging of the medium. HEPA filters shall be mounted so the faces are perpendicular to the ground whenever possible. If they must be mounted with the face parallel to the ground, then the upstream face side should face down so airflow will work against sag.

Open-face filters. Gasketed open-face filters shall be supported and clamped perpendicularly to a flat, rigidly constructed mounting surface. The mounting surface should have a finish of 125 microinches and a plane within 1/16-in. total tolerance. See Section 2.4.5 for information about clamping arrangements.

Blu-Jel (or equivalent) fluid seal style open-face filters shall be installed in accordance with instructions from the filter and housing manufacturers.

Closed-face filters. Closed-face filters are furnished with reducing fittings that have cylindrical ends. The filter unit is installed in-line between two sections of duct and connected by flexible joints made of fire- and chemical-resistant elastomer. Each joint is secured with adjustable stainless steel clamps. Closed-face filters are no longer allowable, as stated in *Lawrence Livermore National Laboratory HEPA Filter and In-place Leak Testing Standard (*UCRL-AR-133354) and the references in Section 5.0. Therefore

- New installations shall not use closed-face filters for Type III radiological workplaces or where the filter is intended to prevent discharges of aerosols that may subject workers, the public, or the environment to levels above recognized exposure standards, regulatory emission levels, or Laboratory requirements.

Note: Closed-face filters can be used for applications such as housekeeping filters placed on the exhausts of gloveboxes as these filters are not normally used alone to prevent discharges that are potentially hazardous to people or the environment.

- Open-face filters shall replace closed-face filters in existing installations. Closed-face filters do not conform to the requirements of ASME N509 (*Nuclear Power Plant Air-Cleaning Units and Components)* or DOE-STD-3020-97 (*Specification for HEPA Filters Used by DOE Contractors)*. The plan for implementing *HEPA Filter and In-place Leak Testing Standard* (UCRL-AR-133354) is provided in Appendix B.

2.4.2 Mechanical Characteristics

The resistance to airflow through a new filter unit is approximately 1.0 in. wg at the rated flow. Filter replacement is typically recommended when the pressure drop across the filter is about 4 in. wg at the rated flow or when the flow decreases below an acceptable level. The HEPA filter must be replaced before the pressure drop exceeds 5 in. wg. A standard for the maximum allowable pressure drop that prompts filter replacement shall be developed for separatorless filters based on manufacturers' guidance.

Stock filter units are all inspected by the manufacturer for materials and construction compliance. Before filters are shipped, tests are conducted to verify the filter's flow resistance and filtration efficiencies. All LLNL stock filters are retested for pressure drop and efficiency and checked for workmanship and material conformance by a DOE filter testing facility.

The following engineering information shall be marked on the frame of each filter unit:

- Percent penetration at rated flow.
- Resistance at rated flow.
- Direction of flow.
- Filter size.
- Type of separator.

2.4.3 Loading and Efficiency

The dust-holding capacity of a filter is dependent on the shape, size, and density of the dust particles it is exposed to. In applications with high dust concentrations, the HEPA filter should be protected by replaceable prefilters upstream of the filter. For structural design purposes, 4 lb of dust load per 1000 cfm of rated capacity can be assumed.

2.4.4 Adverse Operating Conditions to Be Avoided

Continuous exposure to the operational environments listed in Table 2 will permanently damage or compromise the HEPA filter.

Table 2. Conditions that will damage HEPA filters.

- **Moisture: 95-100% relative humidity.**
- **Hot air: greater than 275 °F.**
- **Fire: direct fire or high concentrations of particulate matter produced by fire.**
- **High pressure: 8 in. of water, gauge (in. wg) internal or differential across filter media.**
- **Corrosive mist: dilute moist or moderately dry concentrations of acids and caustics.**
- **Any acid and some caustics will attack uncoated aluminum separators.**
- **Hydrofluoric acid will attack the media.**
- **Nitric acid will attack wooden boxes making highly flammable nitrocellulose.**
- **Shock pressures.**

Note: The filter exterior must not be exposed directly to outdoor environments.

2.4.5 Housings and Clamping Arrangements

Based on the hazardous ventilation condition identified in the safety evaluation, the Hazards Control Department will assist in determining the need for and the type of prefilter and HEPA filters for the system. HEPA filters are used in supply, exhaust, recirculation, and cleanup systems. Depending on the system requirements, installation of the HEPA filter may require a single- or two-stage installation, and depending on the system's airflow volume requirement, each stage may consist of a single filter unit or multiple units.

Open-face filters shall be installed in totally enclosing housings. The housing shall be designed with a long transition from duct to housing to promote uniform airflow through the filter(s). HEPA filters and other system components shall be designed to withstand peak pressures in accordance with Section 4.6.5.4 of ASME N509-1989 (*Nuclear Power Plant Air-Cleaning Units and Components).* The housing design and filter arrangement within the housing shall allow air to enter and exit the housing without changing direction. Housing design guidelines are provided in ASME N509 and the *Nuclear Air Cleaning Handbook*. The following is a summary of these guidelines:

- Standard LLNL stock HEPA filter sizes shall be used as they are, without requiring modifications, special attachments, or devices for installation other than the bag-in/bag-out housing. Filter housing shall be of welded construction, and all weld joints and seams shall be continuously welded. All weld joints shall be visually inspected for cracks, underfill, incomplete fusion, overlaps, surface porosity, gas pockets, crevices, pits, and depressions. (Flawed units shall not be installed.) All joints and seams shall be ground smooth, and all burrs and sharp edges shall be removed.

- Interior surfaces of the filter housing shall be smooth and made of impervious material as free of cracks, crevices, and hard-to-reach spaces as possible. Matt texture and colors that hide dust should be avoided.
- Filter housings and all hardware on the housings and mechanical components of the filter clamping mechanisms shall be made of materials or coating suitable to the system's design requirements. (Stainless steel filter frames are typically not painted.) The clamping mechanism should be designed to exert 20 to 25 pounds per square inch of gasket area or a total loading of about 1400 pounds delivered to the clamping surfaces of a 24 × 24-in. filter. The force is designed to compress the gasket uniformly by approximately 50% of its 1/4-in. thickness. The filter shall be retorqued one or two weeks later to a total gasket compression of about 80%. An alternative method of assuring adequate compression uses spring-loaded pusher plates as described in "Spring-Loaded Hold-Down for Mounting HEPA Filters at Rocky Flats"[1]. Clamping devices must function easily and reliably; the clamping force must not distort or break the filter frame. The knife-edge sealing mechanism is designed for use with flexible-skinned capsules containing Blu-Jel (or equivalent) filler that perform the same sealing function as gaskets. The knife-edge sealing mechanism cannot be used with the rubber-gasket seal filters.
- Where significant contamination is possible, the filter should be mounted on the downstream side of the mounting frame. This minimizes surface contamination on the filter and allows filter replacement activity on the clean side. For other uses, the filter mounting may be on either the upstream or downstream side of the mounting frame.
- Housings designed for filter bag-out services shall have a removable access door and bag-out port for each tier of filters. Bag-out mechanisms and devices for the process shall be designed for reliable and safe operation.
- Filter housings, together with internal assemblies, shall be designed to withstand seismic loadings.
- Filter housings shall also be manufactured under a quality assurance plan and tested for filter fit, leak-tightness, and operation of the filter clamping mechanism before leaving the factory. Housings shall not be manufactured at LLNL or at vendors other than the HEPA filter manufacturer or vendors approved by the HEPA filter manufacturer. Manufacturers of HEPA filter housings shall meet the requirements in ASME N509 (*Nuclear Power Plant Air-Cleaning Units and Components)*. The manufacturer or manufacturer-approved vendor is able to deal with the distortion of the housing material caused by manufacturing processes such as welding and grinding that could compromise obtaining a proper seal when the HEPA filter housing is in use. The

manufacturer is required to perform a series of tests on the filter housing according to ASME N509 and ASME N510 (*Testing of Nuclear Air-Cleaning Systems)* and shall provide a copy of the test results with the housing delivery.

2.4.6 Performance Monitoring Provisions

Magnehelic or other alternative pressure gauges shall be installed across the filter or filter banks if the filter or filters are the last or next to last stage of filtration before discharge to the environment or if the filter or filters could experience sudden pressure fluctuations or sudden loading. These instruments will be used to indicate pressure drop across the filter, which will help determine the extent of dust loading or failure due to rupture. The instrument display(s) shall be located in the work area for easy and frequent observation, if practical. The instrument display(s) shall be clearly labeled with a plain language description of function. Flow measuring devices should also be installed to reduce the possibility that the flow may decrease to unacceptable levels while the pressure differential reading remains acceptable. The instruments shall be suited for the anticipated range of pressures or velocities and the displays shall be marked in units that are easily read. The instruments and readouts shall be calibrated at least annually.

HEPA filters for radiological Type III workplaces shall be equipped with a differential pressure gauge, preferably of the alarming type.

2.5 HEPA Filter System Testing

Installed HEPA filters shall be tested in-place upon installation, before initial use, and at least annually thereafter. In-place HEPA filter testing involves testing the filter system together with the associated ducting system. Parallel-flow systems may require shut off of one side for testing and replacement so as not to interrupt airflow. The Hazards Control Industrial Hygiene Instrument Laboratory performs this test at least annually on all active toxic and radioactive HEPA filter systems that are the last or next to last stages of filtration prior to discharge to the environment and for some selected systems that would have major consequences if the filters leaked, as requested by the directorate. More frequent testing may be done when the airstream is unusually dusty or corrosive. Inactive systems should not be tested and are labeled accordingly. Housekeeping filters are also not tested. The Hazards Control Industrial Hygiene Instrument Lab maintains a log of when filters are installed, changed, and/or tested, and the results of those tests.

In-place tests of HEPA filter installations are made with an aerosol of PAO that has a controlled distribution of droplet sizes. To obtain a proper mixing of the aerosol and air, the PAO is injected upstream of the filters with the system's fan operating. An aerosol photometer measures representative concentrations of PAO upstream (unfiltered air) and downstream (filtered air) of the filters. The HEPA filter and its installation are acceptable

if the percent leakage is equal to or less than 0.03% or other value less than 0.05% and specified in an approved Technical Safety Requirement or other appropriated safety basis document. If the in-place leakage exceeds 0.03% or other specified value and cannot be adjusted by correcting the sealing clamps, the HEPA filter shall promptly be replaced. When possible, the filter system shall be checked for filter leaks or seal bypasses. After the defect is discovered and repaired or the filter replaced, the filter system is retested.

Depending upon the design requirements, the filter system may require a single- or two-stage arrangement; each stage may require one or more filters. To perform a valid in-place test at a HEPA filter installation, proper mechanical details must be incorporated in the complete ventilation system to assure that the system can be quantitatively tested for penetration. This means that the PAO aerosol must be mixed so the concentration upstream of the filter system is within ±20% of the average concentration and remixed so concentration measurements downstream of any stage of HEPA filtration are reproducible within ±5% of two or more measurements at up- and downstream locations made during a measurement session at each filter test location. (See Appendix C for specific requirements about assuring that these conditions can be met.)

2.6 System Operation

2.6.1 Periodic Inspection

All ventilation systems with HEPA filters installed outdoors or in places where they can be damaged by weather or other agents such as moisture, corrosion, or vehicle traffic shall be inspected quarterly. The filter housing shall be examined for signs of warping, water damage, or separation of the frame. The connections shall be checked for a tight fit, boot decay, and secure clamps. Because these are potentially high-hazard exhaust systems, the ductwork shall be examined for signs of corrosion, wear, and new penetrations. **Results shall be documented in an easily accessible manner.** Management authorizing the use of walk-in plenums and other systems that are protected from weather and damage by other agents shall ensure they are inspected annually.

The pressure- and airflow-gauge readings shall be recorded before a system served by HEPA filters is operated and monthly thereafter. The timing of pressure gauge readings shall be decided jointly by the user and the Hazards Control Department. A sudden, large drop in differential pressure strongly suggests the filter has undergone a large penetration or a structural failure. If such a pressure drop occurs, stop operations and contact the area ES&H Team for an evaluation. Filter loading occurs very slowly at first, then increases rapidly once the system's threshold has been reached. Contact the design engineer or your ES&H Team industrial hygienist to determine the acceptable operating pressure range for the installed system. (The acceptable range is different for each system, depending on the system layout and fan size.) The system's log of pressure drop readings will provide advance indications when rapid increase in drop may begin.

2.6.2 Avoiding Operation Under Adverse Conditions

Filter media and frame components have marginal resistance to constant exposure to adverse environments. Avoid conditions listed in Table 2.

2.6.3 Filter Changes

Filters that are not expected to be significantly contaminated are changed by

- Area ES&H Team health and safety technicians—Buildings 251 and 332
- Air Conditioning Shop—remainder of the Livermore site
- Maintenance mechanics—Site 300

Filters that are expected to be significantly contaminated are changed by the area ES&H Team health and safety technicians.

The area hazardous waste management (HWM) field technician shall be contacted prior to any filter change-out to facilitate adequate characterization for safe treatment, storage, and disposal.

WARNING!

The separators in filters made prior to 1984 often contained asbestos so exercise care when handling any older filter.

2.6.4 Labeling HEPA Filters That Will Be Discarded

In addition to the labeling requirements in the HWM *Waste Acceptance Criteria* (UCRL-MA-115877), any HEPA filter, and associated prefilter that will be discarded shall be labeled as shown in Fig. 2 as early as possible. The label should be affixed to the filter when it is installed and shall be affixed either to the filter or the plastic bag in which it is shipped when the filter is removed. The label shall be affixed by the user organization or ES&H Team health and safety technician supporting the user organization.

2.6.5 Filter Replacement

HEPA filters shall be replaced when:

- The filter fails the PAO test and cannot be brought into compliance.
- The casing is deteriorated by corrosion or, for wooden filter housings, prolonged contact with water sufficient to infiltrate the plywood casing material.
- Pressure drop across a filter exceeds 5 in. wg.

Figure 2. Label for HEPA filter that will be discarded.

- The filter was exposed to:
  - — Water spray without protection by a demister or any time a filter is exposed to water spray from fire fighting.

- — Moisture: 95-100% relative humidity at temperatures higher than 130°F.
- — Hot air: higher than 275°F.
- — Fire (direct contact).
- — Shock pressures greater than 1.7 psig.

Filters subjected to smoke from fires shall be PAO tested immediately and replaced if pressure drop is excessive or if the filter fails the PAO test.

HEPA filters shall be replaced ten years after the date of manufacture. The exceptions to this requirement are:

- Any such filter that has become soaked or which could have become soaked, as from the activation of an in-duct water sprinkler or from spraying water directly on the filter, shall be replaced promptly.
- Any such filter that could become soaked, as from the activation of an in-duct water sprinkler, shall be replaced within five years of the date of manufacture.
- If the manufacturing date is not available, HEPA filters shall be replaced after five or ten years, as applicable, from the date of original certification at a DOE filter test facility.

3.0 Responsibilities

All workers and organizations responsible for HEPA filter system design for LLNL applications shall refer to Document 2.1, "Laboratory and ES&H Policies, General Worker Responsibilities, and Integrated Safety Management," in the *ES&H Manual* for a list of general responsibilities. Specific responsibilities are listed below each title.

3.1 Plant Engineering or Other Design Organizations Designing HEPA Filter Systems

Plant Engineering and design organizations shall:

- Ensure that HEPA systems are designed to comply with the requirements specified in this document and referenced standards.
- Provide user groups with information regarding the acceptable operating pressure range and minimum flow rate for the installed system.

3.2 User Organizations

User organizations shall:

- Ensure that HEPA filters are used in accordance with this document.
- Assist the Hazards Control Department in testing HEPA filters when they are installed and annually thereafter as necessary.
- Coordinate with Plant Engineering or other design organizations, Procurement and Materiel, and the ES&H Team to assure HEPA filtration systems are properly designed in accordance with this document and supporting WSSs.
- Inspect HEPA filter systems for pressure drop and physical condition as specified in Section 2.6.1.
- Label HEPA filters installed on HEPA filter boxes that were first or second downstream from a glovebox containing radioactive, carcinogenic, or biohazardous materials being disposed of as hazardous waste. (See Figure 2.)
- Keep a record of the materials processed by the activity/equipment served by a HEPA filter or HEPA filter system sufficient to allow characterization of the filter contents when it is disposed of.

3.3 Hazards Control Department

3.3.1 Safety Programs Division

The Safety Programs Division shall:

- Advise Procurement about stock levels of HEPA filters to be maintained.
- Provide ongoing technical guidance to the ES&H Teams and the Industrial Hygiene Instrument Lab.

3.3.2 Industrial Hygiene Instrument Laboratory

The Industrial Hygiene Instrument Laboratory shall:

- Review all proposed procurements of HEPA filtered vacuum cleaners and similar equipment.
- Test new HEPA filters and filter systems upon installation, before initial use, and at least annually thereafter and report results to the facility points of contact and area ES&H Teams.

- Document compliance or noncompliance of new and modified HEPA filter systems with the requirements of this document and the references cited in Section 4.0 by forwarding the results of measurements to the area ES&H Teams.

3.3.3 ES&H Team Industrial Hygienists/Health Physicists

The ES&H Team industrial hygienists/health physicists shall:

- Advise users when HEPA filters are needed or are no longer needed.
- Advise facility points of contact of the results of HEPA filter testing for existing systems, new filters installed in existing systems, modifications to existing systems, and new systems.
- Advise facility points of contact of any corrective actions suggested by HEPA filter testing results.

3.3.4 ES&H Team Health and Safety Technicians

The ES&H Team health and safety technicians shall:

- Assist Industrial Hygiene Instrument Laboratory personnel and assure in-place filter testing can be done safely.

3.4 Procurement and Materiel

Procurement and Materiel shall:

- Ensure that proper filter specifications are provided to the vendor when ordering filters.
- Ensure that filters and systems meet specification requirements.
- Assure filters are procured and stocked in quantities that are adequate to meet needs.

4.0 Work Standards

4.1 Work Smart Standards

ACGIH, *Industrial Ventilation. A Manual of Recommended Practice,* American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 23rd edition, 1998.

ASME N510-1989, *Testing of Nuclear Air-Cleaning Systems*, Section 10, "HEPA Filter Bank In-Place Test."

DOE-STD-3020-97, *Specification for HEPA Filters Used by DOE Contractors.* (Applies to all open-faced filters.)

UCRL-AR-133352, "HVAC Systems in Nonreactor Nuclear Facilities."

UCRL-AR-133354, "HEPA Filter and In-Place Leak Testing Standard."

4.2 Other Requirements

ASME N509-1989, *Nuclear Power Plant Air-Cleaning Units and Components,* Section 5.6, "Filter Housing."
(Applies only to new filter plenums and as a guide to upgrading existing filter plenums. It does not apply to side-access filter housings but can be used as a guide for them.)

DOE-STD-1066-97, *DOE Fire Protection Design Criteria*, (1997).

DOE-STD-3022-98, *DOE HEPA Filter Test Program*, (1998).

ERDA 76-21, *Nuclear Air Cleaning Handbook*, Chapters 1-3, (1976).

Implementation Plan for LLNL HEPA Filter and In-Place Leak Test Standard (UCRL-AR-133354), 1999.

5.0 Resources for More Information

5.1 Contacts

Alternatives to the recommended designs and additional information related to HEPA filters, system design, installation, and testing is available from

- Industrial Hygiene Instrument Laboratory
- Hazards Control Safety Programs Division

Filter change support is available from

- HVAC Shop (Livermore site)
- Maintenance mechanics (Site 300)

See the ES&H contact list.

5.2 Applicable Lessons Learned

The Lessons Learned Program is available on the Internet at the following URL address:

http://www.llnl.gov/es_and_h/lessons/lessons.shtml.

5.3 Other Sources

5.3.1 Housing Design and Layout

Burchsted, C. A., A. B. Fuller, and J. E. Kahn (1979), *Nuclear Air Cleaning Handbook*, Chapters 4 and 8, U.S. Government Printing Office, Washington, DC, ERDA 76-21.

Terada, K., C. R. Rose, and A. G. Garcia (1985), "Spring-Loaded Hold-Down for Mounting HEPA Filters at Rocky Flats," Proceedings 18th DOE Nuclear Airborne Waste Management and Air Cleaning Conference (U.S. Department of Energy, The Harvard Air Cleaning Laboratory, Baltimore, MD, August 12-16, 1984).

5.3.2 System Testing

Associated Air Balance Council, *AABC National Standards*, Publication MN-1. Associated Air Balance Council, Washington DC, (1989).

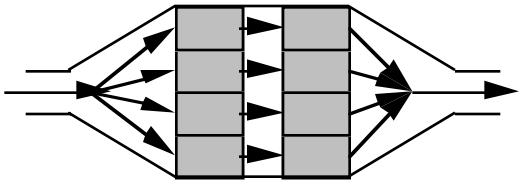
Burchsted, C. A., A. B. Fuller, and J. E. Kahn, (1979) *Nuclear Air Cleaning Handbook*, Chapter 8, U.S. Government Printing Office, Washington, DC, ERDA 76-21.

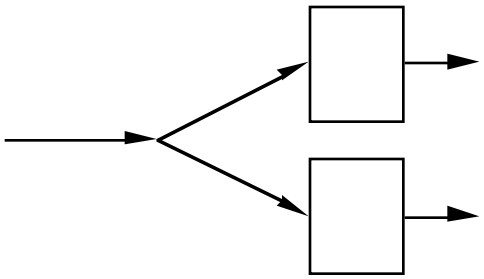
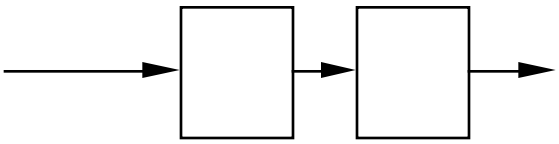
Industrial Hygiene Instrument Laboratory, HEPA Filter Test Procedure, Procedure HEPA 1.0, Revision 5. Hazards Control Department, Lawrence Livermore National Laboratory (1998).

Appendix A

Terms and Definitions

Challenge aerosol	Particles of a liquid or solid dispersed into the air flowing towards a HEPA filter undergoing test. HEPA filter test instruments measure the concentration of aerosol upstream and downstream of the filter. The challenge aerosol used at LLNL is polyalpha olefin (PAO).
Closed-face filter	A filter in which the up- and downstream sides can not be seen because panels cover them. The enclosing panels include ductwork. Also called a "bird cage," "box," "encapsulated," or "flanged" filter. These usually have a fitting on each end that can be connected directly into ventilation system ductwork.
Core	The filtering medium, separator, and material used to attach them to the filter casing.
Filter medium	Material, usually fiberglass, that removes particulate from air.
Highly hazardous	Materials that are significantly radioactive, highly toxic, or biohazardous.
Housekeeping HEPA filter	A HEPA filter installed near the contaminant source to assure that ductwork downstream from the filter does not become contaminated. These are typically, but not always, smaller than the HEPA filters installed to prevent discharges to the environment because they are installed on branches of a ventilation system while filters intended to prevent discharges to the environment are installed in the main ductwork carrying the entire flow of the system. It should be borne in mind that the housekeeping filters are the ones that actually do the job of removing contamination and therefore may have high levels of contamination.

Highly toxic	Substances that are harmful by being Carcinogenic A reproductive hazard Acutely toxic (e.g., by chemical asphyxiation in the case of hydrogen cyanide) Toxic by some other means (e.g., the brain/liver/kidney/blood-forming organ toxicity for lead) The ES&H Team uses Document 14.2, "LLNL Chemical Hygiene Plan for Laboratories," in the *ES&H Manual* for guidance when advising whether a material is highly toxic.
Monodisperse	A population of particles where the diameters are very close to a specified value. (E.g., 0.3 micrometers for particles used to test HEPA filters at a DOE HEPA filter test station.)
Multi-stage	Filters arranged so air travels through more than one bank of filters before exiting as shown (the shaded cubes represent individual filters): 
Nuclear-grade HEPA filter	A filter used for removing particulates from effluent streams that is manufactured in accordance with a specification for filters such as MIL-F-51079 (now cancelled) or DOE-STD-3020-97.
Open-face	A filter in which the entire filter medium can be seen from the up- or downstream side.

Parallel (mounted) filters	Filters mounted so air flows through filters separately as shown:  Compare to series (mounted) filters.
Pleat	A folding of the filtering medium that increases the available surface area. See Fig. 1.
Prefilter	A filter with lower efficiency placed upstream of a HEPA filter to protect the HEPA filter from premature clogging or mechanical damage caused by coarse particles in the air entering the HEPA filter.
Radiological type III workplace	A workplace that provides two barriers between the worker and the material (e.g., a HEPA-filtered glovebox). Such workplaces are appropriate for high-hazard operations where, without the proper controls, workers could incur a significant internal uptake (i.e., a dose greater than the legal limits).
Separator	Material inserted between the pleats of filter medium to add structural strength and provide a spacer between the pleats. See Fig. 1.
Series (mounted) filters	Filters mounted so air from one flows through the other as shown:  Compare to parallel (mounted) filters
Stairmand disk	A partially perforated plate installed in ductwork upstream from a HEPA filter to create turbulence that will ensure challenge aerosol is mixed uniformly. See Fig. C-1a and Fig. C-1b.

Appendix B

Implementation Plan for LLNL HEPA Filter and In-Place Leak Test Standard (UCRL-AR-133354)

Implementation Plan for HEPA Filter Upgrades

Introduction

This Implementation Plan presents a schedule and approach to phase-out many of the HEPA filters and filter systems used throughout Lawrence Livermore National Laboratory (LLNL) that do not conform to the standards outlined in the *LLNL HEPA Filter and In-place Leak Testing Standard*, UCRL-AR-133354 (referred to in this document as the Standards document).

This Implementation Plan applies only to the HEPA filters that are covered in the Standards Document; it is not intended to establish long-term replacement intervals. This plan provides a method to meet testing, filtering, and system upgrades consistent with ALARA, relative to worker safety, environmental compliance, and waste generation. The following filters require phase-out to meet these standards:

- Filters that exceed the replacement age identified in the Standards Document;
- Filter systems that are not in compliance with the Standards Document (e.g., closed-face filters or filter systems without, or incorrectly designed, injection ports for challenge aerosol testing);
- Filter systems in Institutional buildings that are scheduled for D&D; and/or
- Filter systems in facilities that are not operational.

Implementation Schedule

Each Directorate will evaluate its HEPA filter systems and filters to validate the existing database. Table B-1 is a phase-in schedule for implementing the criteria established in the Standards Document; Table B-2 is a decision-basis tool for each Directorate to use that identifies the implementation priority and bases replacement selections on the most conservative priority. For example, if a filter is >20 years old, it has a 2-year replacement priority.

Table B-1. Implementation Schedule—July 1999 through October 2009.

Phase-in Date	Activity
July 30, 1999	• Approve Implementation Plan
Sept 30, 1999	• QA database and identify affected systems (per Directorate) • Establish an Institutional point-of-contact
Mar 30, 2000	• Identify 2- 5- and 10-yr change-out actions (see Table B-2) • Establish a list of needs for filters and system upgrades to prepare a preliminary cost estimate
Sept 30, 2000	• Prepare and submit initial capital funding request
Oct 2001[1]	• Complete 2-yr filter replacements (see Table B-2)
Oct 2004[2]	• Complete 100% of all wet system upgrades and replacement of 5-yr filters (see Table B-2)
Dec 2005[3]	• Implement testing methods
Oct 2009[4]	• Complete 100% of all dry system upgrades and replacement of 10-yr filters (see Table B-2)

1 Anticipate 2 years from adoption date.

2 Anticipate 5 years from adoption date.

3 See Test Methods section of this Appendix.

4 Anticipate 10 years from adoption date.

Table B-2. HEPA Filter Replacement Priority List.[1]

Criteria	Implementation priority for first HEPA filter replacement in systems covered in the Standards Document (UCRL-AR-133354)		
	10 years	5 years	2 years
Age of the filter	<10 years	>10 years	>20 years
Consequence of filter failure	Low	Moderate	High
Filter is the last filter before discharge *and* the probability that it will be challenged by a hazardous discharge or a significant mechanical stress	Low	Moderate	High
Fans are capable of applying >10 inches water gauge	No	—	Yes
Ventilation system has in-duct water sprays (with or without de-misters)	No	Yes	—
The filter shows evidence of physical deterioration or damage	No	—	Yes

1 Closed-face filters can replace closed-face filters, if needed, in the time interval allotted for replacing the HEPA filters shown here.

An exemption will be requested through the WSS Change Control Board for any required upgrades to the HEPA filters in buildings that are scheduled for D&D in five years, mothballed, Institutional legacy facilities, or are being used only for storage of material in sealed containers. Under this proposed exemption, the HEPA filters in these facilities would continue to be replaced in like kind per the schedule defined in this plan. Legacy facilities are formally approved and accepted by the LLNL DDO. Buildings 412, 222, 227, and 251 are designated Legacy facilities.

Roles and Responsibilities

The following roles and responsibilities will be assigned to implement this plan:

- Filter-responsible Directorates shall assess and evaluate their filter systems per this Implementation Plan (see Tables B-1 and B-2) and report the information to the Institutional Facility Manager (IFM) by October 1, 1999. Directorates shall provide assurance that systems identified as needing changes are consistent with the schedule outlined in this Implementation Plan, and that work is coordinated with the Institutional Point-of-Contact (IPOC).
- The Deputy Director of Operations (DDO) shall identify and appoint an IPOC to coordinate funding requests, implementation activities, and provide standardized, Integrated Safety Management System (ISMS)-compliant, cost-efficient implementation guidance.
- The IPOC shall seek funding to embark on a project to develop a testing method that will provide dispersion without modification of the upstream side of the filter.
- Hazardous Waste Management (HWM) shall identify and appoint a HWM–POC to process the waste stream and coordinate analytical support to achieve lowest cost/per unit implementation.
- The Hazards Control (HC) Department shall identify an HC–POC to standardize and track the Institutional HEPA filter database. Additionally, a subject-matter expert shall be identified to support each Directorate in determining applicability of the standard to its systems.
- Plant Engineering (PE) shall identify a PE–POC to provide standardized cost-efficient design, estimating, and construction support to implement HEPA system upgrades in a safe, cost-efficient manner.

Issues Impacting Implementation

Each Directorate needs to evaluate the following issues that may or may not impact the Implementation Plan and schedule for phase-in operations (see Tables 1 and 2). These issues include:

- Exemption Requests
- Test Methods
- Waste Minimization

Exemption Process

Exemptions to upgrades or filter replacement, in systems other than those previously identified, require submitting a request and obtaining the approval of the WSS Change Control Board. The cognizant Associate Director responsible for the filter or system shall submit documented requests for exemption following the process outlines in Document 2.3, "LLNL Exemption Process," in the *ES&H Manual.*

Request for system upgrades exceptions may also be submitted on a case-by-case basis, based on ALARA (see Test Methods below). These exceptions are for upgrading, not for replacing like filters.

Test Methods

Many existing systems do not have compliant injection ports that meet the requirements outlined in the Standards Document and will require modifications. In order to meet the testing quality (ASME N510 equivalent) specified, many of the existing HEPA systems or associated ductwork will need to be modified to provide turbulence in either the upstream, downstream, or both air streams. Where these modifications may cause unnecessary ES&H risks solely for the purpose of modifications to comply with the challenge aerosol test standard; the ALARA principle will be utilized to schedule the upgrade.

Waste Minimization

HEPA filter replacement and duct system replacements/upgrades shall be coordinated to minimize the creation of unnecessary waste streams.

Appendix C

Criteria for Assuring HEPA Filter Systems Can Be Adequately Evaluated

C.1 Objectives

This document specifies how HEPA filters are to be tested after any required upgrades are made to the filter systems so they can be tested in accordance with ASME N509 (*Nuclear Power Plant Air-Cleaning Units and Components)* and N510 (*Testing of Nuclear Air-Cleaning Systems)* or equivalent AG-1 (*Code on Nuclear Air and Gas Treatment)* standards. Filter systems not meeting the upgrade requirements will be tested using the Industrial Hygiene Instrument Laboratory HEPA filter test procedure until the upgrades are completed.

Work smart standard *HEPA Filter and In-place Leak Testing Standard* (UCRL-AR-133354 Rev. 1), is a commitment to comply with portions of ASME N509 and ASME N510 to assure that:

- A quantitative measurement of leakage through a HEPA filter system can be made.
- Challenge aerosol concentrations are ±20% of average at measurement locations upstream of any stage of HEPA filtration to assure that quantitative measurements are made.
- Test methods are as equivalent to those specified in Section 10 of ASME N510.

In general, these criteria are met by assuring turbulent airflow where the challenge aerosol is injected upstream of a HEPA filter and subsequently becomes well mixed downstream from the HEPA filter before reaching the measurement location.

C.2 Advice About Filter Testing

Consult Hazards Control's Industrial Hygiene Instrument Laboratory before completing the test design to assure that a proper method is used.

C.3 Criteria

C.3.1 Injecting Challenge Aerosol

The polyalpha olefin (PAO) aerosol is injected into the ducting through one of the following:

- An injection port. The port should be made of at least 1-in.-diameter, male pipe nipple with a cap. (Ventlock instrument test hold, or equivalent). PAO aerosol can be injected directly into the ducting if there are no other air branch intakes to appreciably dilute the injected aerosol between the injection port and the upstream sampling port and the PAO will be adequately mixed by the time it reaches the upstream measurement location provided the airflow is turbulent. Adequate mixing is assured by placing the injection point at least six duct diameters upstream of the upstream measurement location.
- An injection manifold designed and installed in accordance with ASME N509.

Challenge aerosol can also be injected at the origin of the ventilation system, for example in a lab hood or vented enclosure served by a HEPA filter system. This can be done when both of the following conditions are met:

- There is no contamination hazard for HEPA filter test workers.
- The ventilation system has changes in duct cross section, elbows, or other features that assure that adequate mixing will occur between the aerosol injection point and the upstream measurement location.

C.3.2 Assuring Proper Test Conditions Upstream of HEPA Filters

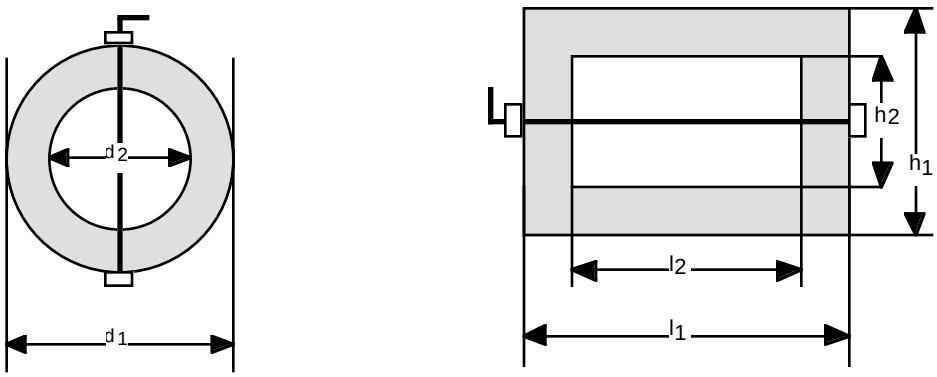
Turbulent flow upstream of HEPA filters can be assured by:

- Significant changes in duct cross section after or at the injection point but before the test point.
- Elbows or bends in ductwork after or at the injection point but before the test point.
- Aerosol injection within a hood or work enclosure where an abrupt change of enclosure/duct configuration occurs as the airflow leaves the hood/enclosure and enters the ductwork.
- A testing system designed and built by the filter or housing manufacturer and which the manufacturer will certify as being in compliance with N509 and testable in accordance with N510 (or the equivalent requirements of AG-1) with ES&H Team concurrence.

Proper mixing of challenge aerosol upstream of HEPA filters can be assured by:

- Having at least six duct diameter separation between the turbulence point and the test point.
- Having at least three duct diameter separation between a Stairmand disk or equivalent in-duct turbulence source, as shown in Fig. C-1a and Fig. C-1b, and the test point.

A testing system designed and built by the filter or housing manufacturer and which the manufacturer will certify as being in compliance with N509 and testable in accordance with N510 (or the equivalent requirements of AG-1) shall be installed. If a factory-authorized testing system cannot be installed, the distribution of challenge aerosol shall be tested on a one-time basis as described below to document that adequately uniform mixing has been attained. The test must be repeated if the system is modified in a way that affects airflow.



$$d_2 = d_1/2^{0.5}$$

$$l_2 = l_1/2^{0.5}$$

$$h_2 = h_1/2^{0.5}$$

$$2^{0.5} \approx 1.414$$

Figure C-1a. Examples of Stairmand disks. The "disk" blocks half of the airflow opening. It is pivoted so it does not block airflow when testing is not in progress.

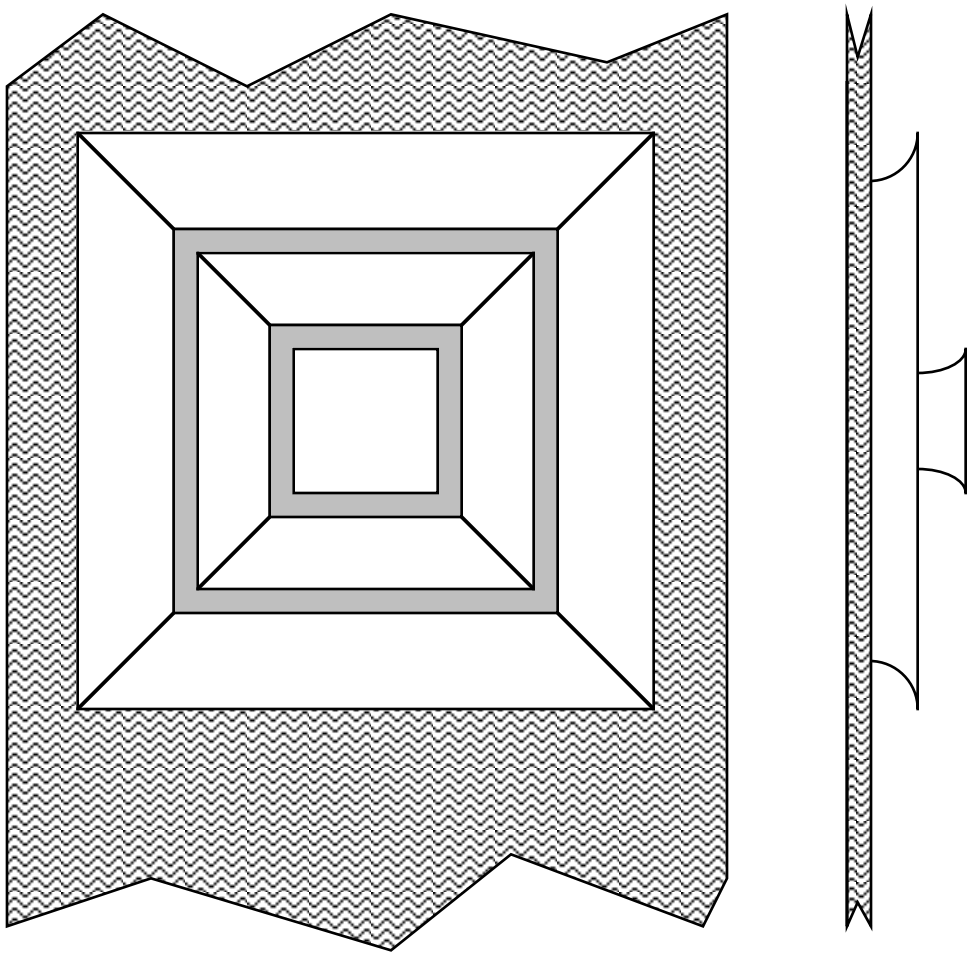


Figure C-1b. Diffuser type flow distributor used by Flanders to promote upstream mixing in HEPA filter housings.

- Taking documented proof measurements at the plane of measurement upstream of the HEPA filter. For the purpose of planning the locations and designs of test ports, the assessment protocol is to use a four-axis grid. The four axes are

  x – horizontal
  y – vertical
  a – 45° between x and y
  b – 90° from the a-axis

- The measurement distances shall follow the guidance of the ACGIH *Industrial Ventilation Manual*, as shown in Fig. C-2, used to select pitot traverse points. If measurements made on the x- and y-axes are ±20% of the average and no evidence of meandering or pocketing is found, then measurements along the a- and b-axes are unnecessary.

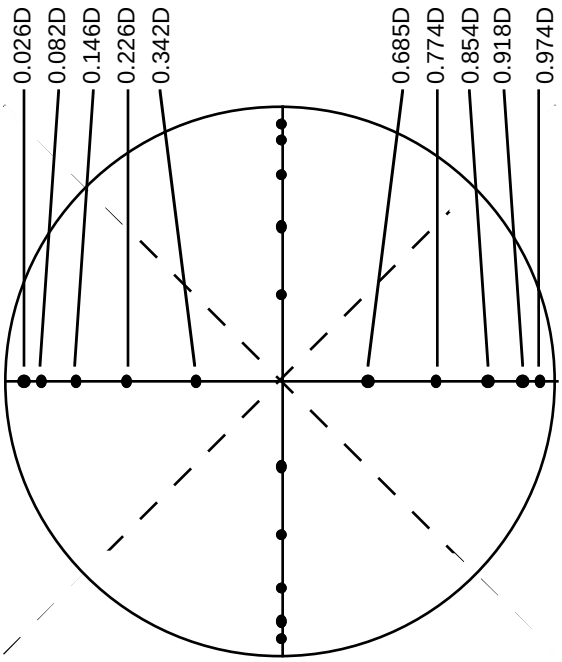


Figure C-2. Measurement points for one-time verification of aerosol distribution uniformity test. Pitot traverse points used for aerosol distribution verification in round ducts. The standard axes are the vertical and horizontal "x" and "y" axes. The dashed lines represent additional "a" and "b" traverse axes that may be needed to verify flow distribution in some installations. D is the duct diameter. The number of readings on each axis for round ducts varies as shown in Table C-1.

Table C-1. Number of pitot traverse points in round ducts for various duct diameters.

Duct diameter (inches)	Number of pitot traverse points
< 10	6
10 ≤ x ≤ 12	8
> 12	10

C.3.3 Assuring Proper Test Conditions Downstream of HEPA Filters

This is more difficult than the upstream cases because the airflow leaving a HEPA filter is laminar. Turbulent flow downstream of HEPA filters can be assured by:

- Measuring downstream of the fan. The airflow before the fan must be measured and compared to the airflow after the fan to assure that the fan is not adding additional diluting air that will create a falsely low downstream reading.
- Elbows or bends in ductwork after the filter but before the test point.

- Placing a Stairmand disk or equivalent in-duct turbulence generator downstream of the filter.
- A testing system built by the filter or housing manufacturer and which the manufacturer will certify as being in compliance with N509 and testable in accordance with N510 (or the equivalent requirements of AG-1) with ES&H Team concurrence.

Proper mixing of challenge aerosol downstream of HEPA filters can be assured by having at least six duct diameter separation between the Stairmand disk or turbulence generator and the test point.

- A testing system built by the filter or housing manufacturer and which the manufacturer will certify as being in compliance with N509 and testable in accordance with N510 (or the equivalent requirements of AG-1) with ES&H Team concurrence.

Turning vanes can be installed to avoid meandering of airflow downstream from an abrupt turn as shown in Figure C-3. The abrupt turn induces turbulence, but meandering will cause a non-uniform distribution of airflow. Non-uniform airflow will cause a non-uniform distribution of aerosol.

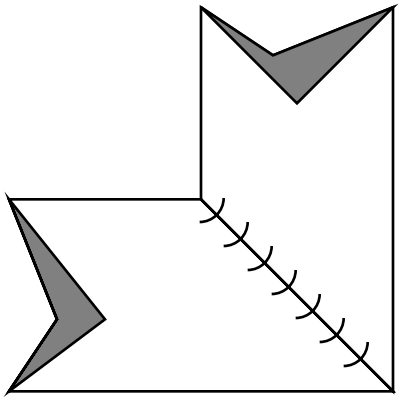


Figure C-3. Turning vanes.

C.4 Special Considerations for Sets of HEPA Filters Installed in Series

Filters in series in a housing equipped with a testing system designed and built by the filter or housing manufacturer and which the manufacturer certifies as being in compliance with N509 and testable in accordance with N510 (or equivalent AG-1 criteria) are an acceptable means of assuring that filters can be adequately tested with ES&H Team concurrence. Alternatively, filter systems can be upgraded following the guidance in Section C.3 to assure adequate turbulence and mixing between the filter stages.

C.5 Scanning

Scanning is not acknowledged by N509, N510, and AG-1 methodology for measuring leakage through a HEPA filter system, but it can be used to obtain supplemental information such as the location of leaks. Uses include detection of a pinhole leak in a filter (which is an indication that the filter needs to be replaced) and finding the location of a leak in a filter bank. The duct wall penetration needs to be as thin as possible during testing, preferably flush with the duct wall, to assure that >95% of the duct area can be reached by the probe. Graphic analysis can be used to determine the fraction of the duct area accessible to scanning, as shown in Fig. C-4. The devices used to protect the penetrations when testing is not in progress must be durable and sturdy enough to remain unattended for a year between tests. Scanning speed shall not exceed one inch per second at the probe tip.

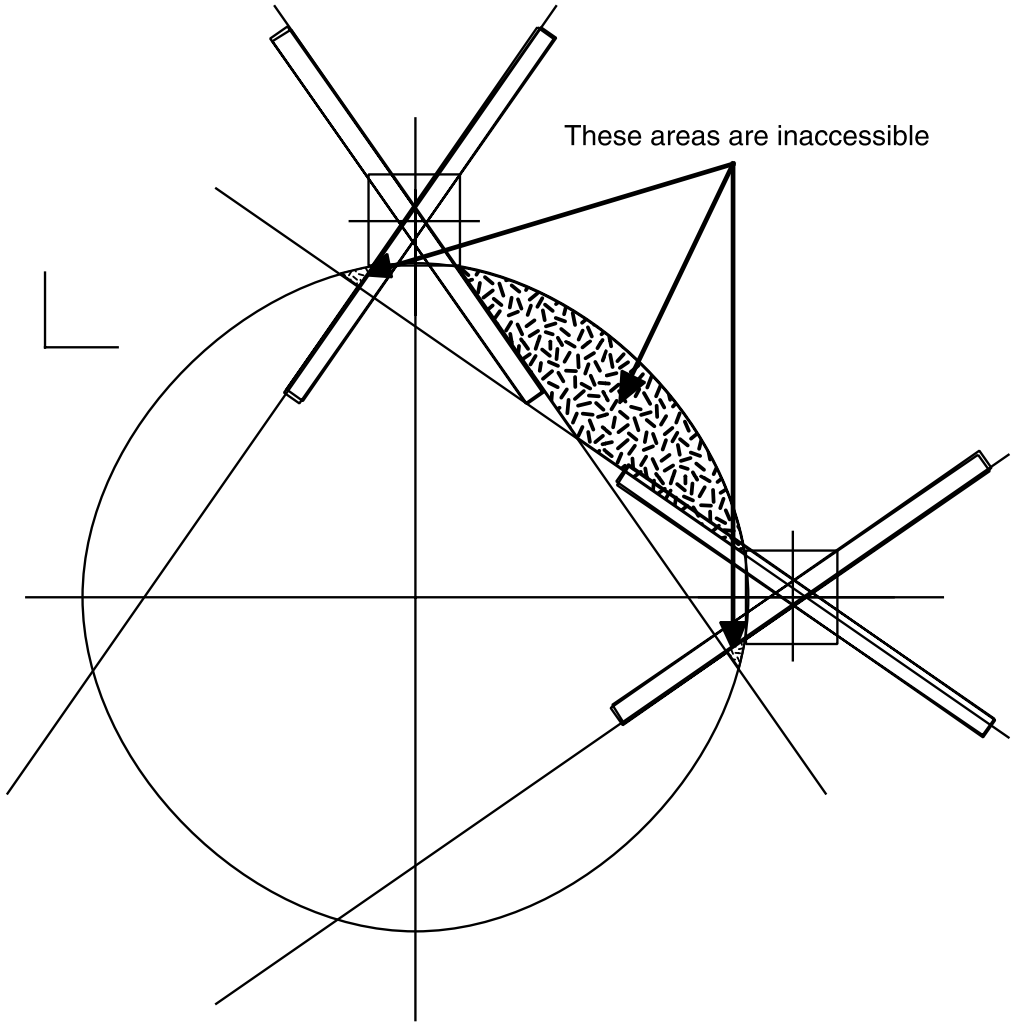


Figure C-4a. Graphic analysis for 1.25" deep ports, 1.25" diameter and a 9" diameter duct. Graphic analysis shows about 8% is inaccessible. It may be necessary to add more test ports. Probe diameter = 1/4".

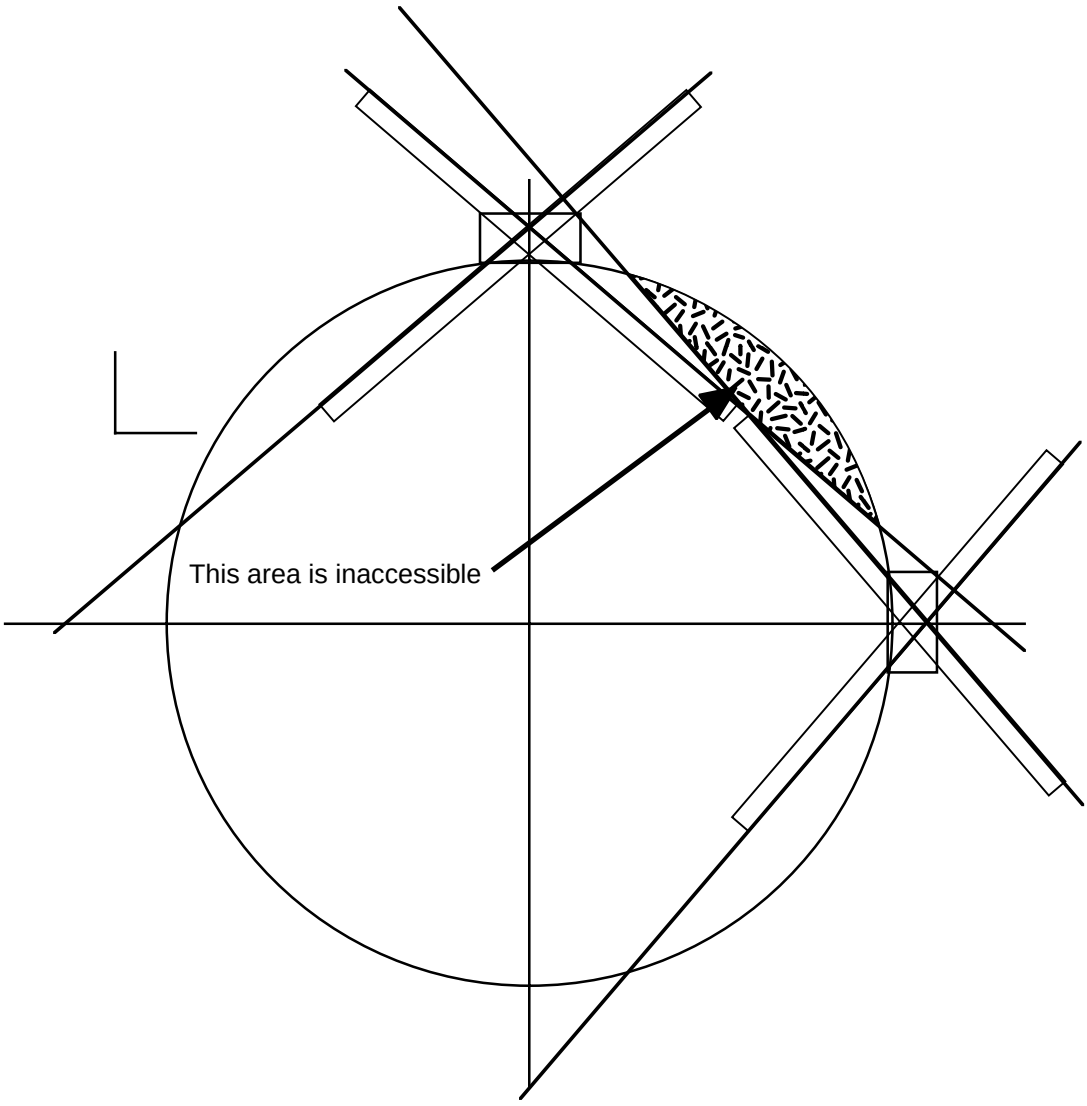


Figure C-4b. Graphic analysis for 0.5" deep ports, 1.25" diameter and a 9"diameter duct. Graphic analysis shows about 3 1/2% is inaccessible. Probe diameter = 1/4".

Plans are being made to upgrade a number of HEPA filter systems as specified in Appendix B. Testing arrangements should be upgraded at that time. In cases where the filter arrangement is satisfactory, but the testing arrangement is not, the testing arrangement upgrade can be scheduled with other ventilation upgrades or prioritized on the basis of the overall importance of the HEPA filter system to either the organization owning it or the entire Laboratory.

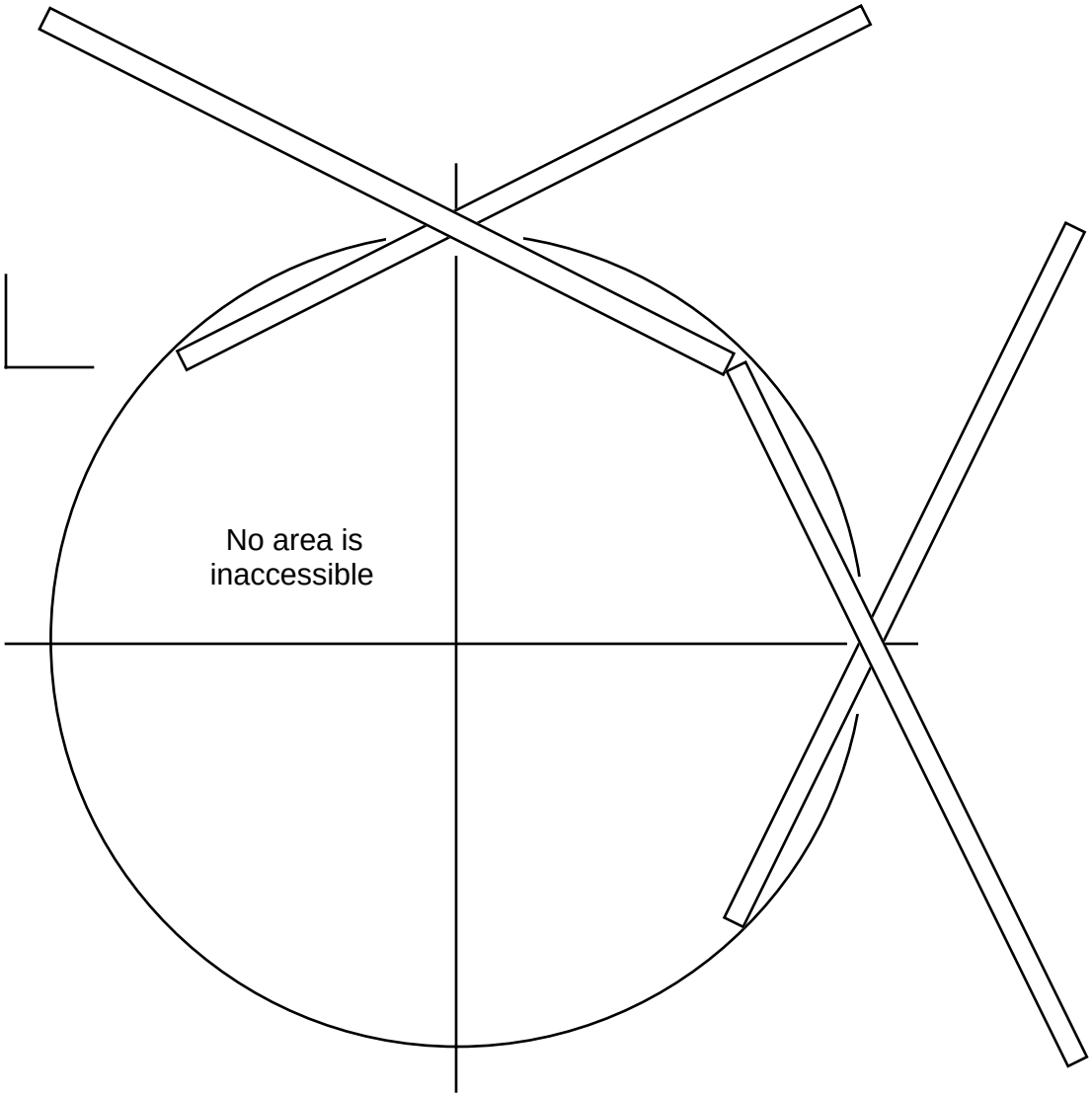


Figure C-4c. Graphic analysis for 0" deep ports, 1.25" diameter and a 9" diameter duct. Graphic analysis shows all parts are accessible. Probe diameter = 1/4". Half scale.

C.7 Working Spaces Inside Larger HEPA Filter Housings

New HEPA filter installations should be designed so workers do not need to enter the housing for filter systems with significant potential for contamination and otherwise whenever practical, to minimize exposure to ionizing radiation and toxic materials. But if this cannot be done, the following requirements apply to HEPA filter housings that workers enter to leak-test filter systems:

- There shall be adequate room and safe working conditions leading to and around the filter installation for test workers and equipment.

- Viewports shall be located on each side of the filter bank for visual inspection.
- Lighting inside the housing shall comply with the requirements of ASME N509-1986. Interior illumination shall be 5 foot-candles or greater.
- Lights that are replaceable from outside of the housing shall be installed in vapor-tight globes.
- Power outlets (110 VAC) shall be provided inside the housing on both sides of the filter for testing equipment. A plant-compressed air supply, if possible, should be convenient to the filter installation. Penetrations shall meet the requirements of ASME N509-1986.
- All wiring and housing structural reinforcement shall be installed on the outside of the housing.
- A pressure-drop measuring device shall be installed near the housing door so that it is readily accessible to monitor the pressure drop across each filter bank. This device must be protected from sunlight and weather.
- Housing doors shall meet the requirements of ASME N509-1986.
- The housing shall open to an area that can serve as a workspace during filter changes.
- A flow-measuring instrument shall be mounted in the exhaust duct downstream of the filter bank for new filter installations and major modifications to existing systems and should be mounted in the exhaust duct of existing installations. It should be located about where the downstream sampling port is located.
- A sampling port shall be located upstream of the HEPA filter bank and downstream of the prefilters for upstream measurements of challenge aerosol concentrations.
- A minimum 40-in. space with adequate height is required to accommodate the test operator along with his/her shroud or multiple sampling equipment. Additional width is needed for filter installation and removal. See Chapter 4 of the *Nuclear Air Cleaning Handbook* (ERDA 76-21), for details.

Test manifolds and turbulence-inducing devices should be designed to swing out of the airflow or to an alignment which induces minimum flow resistance during routine operations. The manifolds and turbulence-inducing devices are swung into the airflow during testing. Workers shall not be subjected to hazards while aligning the test manifolds or turbulence-inducing devices.